Lessons Learned from Major International CCS Demonstration Projects

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ALSTOM
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power generation group
BG GROUP
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CEZ GROUP
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L'ENERGIA CHE TI ASCOLTA.
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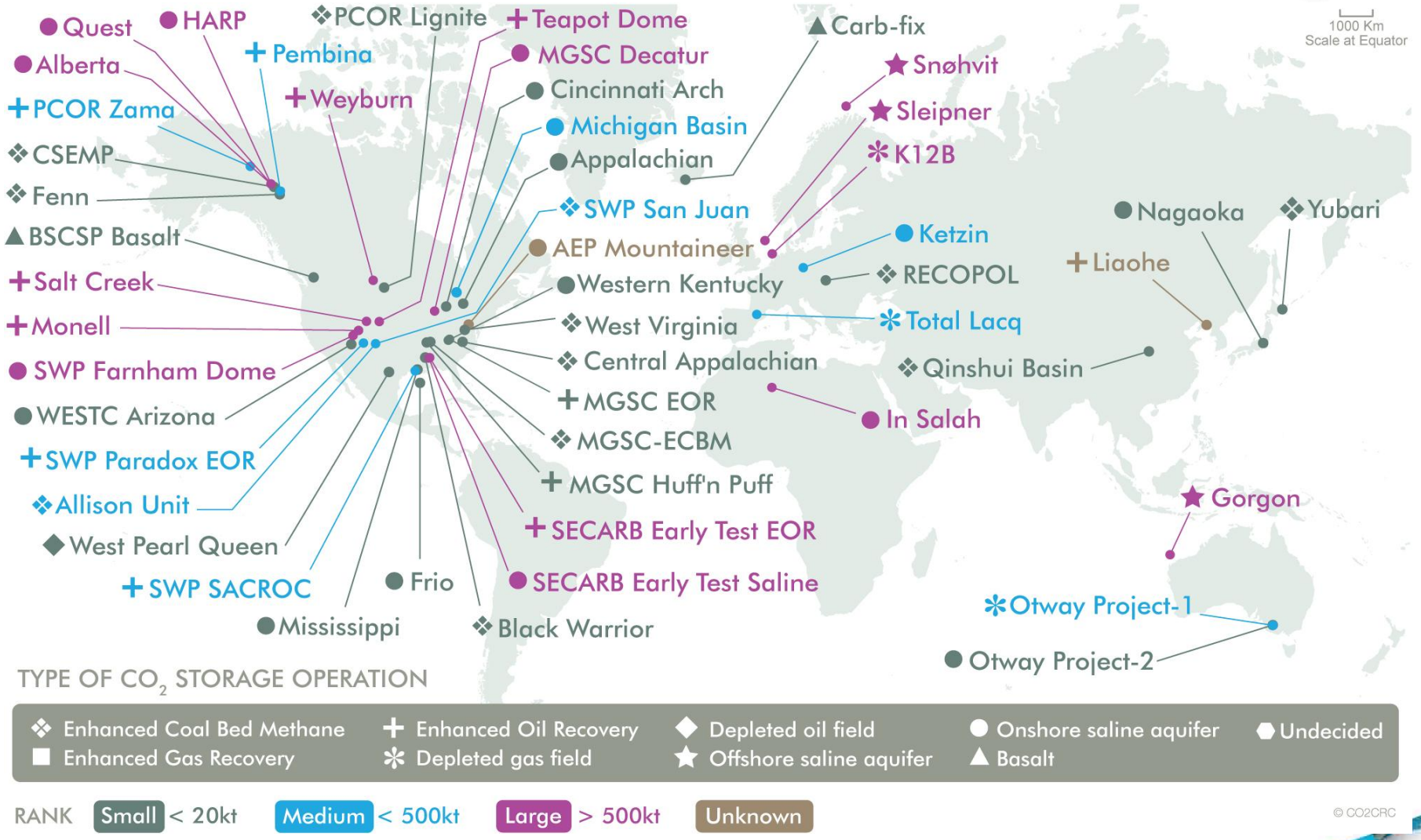
Learnings from Projects

- IEAGHG has assessed the existing body of knowledge on CCS
  - Industrial scale projects around the world that encompass parts of the CCS chain
  - Not fully integrated projects
  - Repeated on a 2 year cycle
- Provide an overview of that work supplemented in cases by other IEAGHG work

Capture project activity

Storage Project Activity



Criteria for large-scale operational projects

- Indicative criteria defined for ‘large-scale operational projects’
- Was, or had been, operational by the end of 2008, and either:-
  - Captured over 10,000 tCO_2 per year from a flue gas
  - Injected over 10,000 tCO_2 per year with the purpose of geological storage with monitoring
  - Captured over 100,000 tCO_2 per year from any source
- *Commercial CO2-EOR was excluded unless there was a monitoring programme to provide learning*
- *Did not need to be fully integrated*
- Added term ‘*large-scale operational*’ to IEA GHG Projects Database

Projects identified (2009)

Bellingham Co-Generation Facility	IFFCO CO_2 Recovery Plant - Aonla
Castor Project	Prosint Methanol Plant
Great Plains Synfuel Plant	Rangely CO_2 Project
IMC Global Soda Plant	Schwarze Pumpe
In Salah	SECARB - Cranfield II
K12-B	Shady Point Power Plant
Ketzin Project	Sleipner
MRCSP - Michigan basin	Snøhvit LNG Plant
Nagaoka	Sumitomo Chemicals Plant
Otway Basin Project	SRCSP – Aneth EOR-Paradox Basin
Pembina Cardium Project	SRCSP – San Juan Basin
Petronas Fertiliser Plant	Warrior Run Power Plant
IFFCO CO_2 Recovery Plant - Phulpur	Weyburn-Midale
Chemical CO. "A" CO_2 Recovery Plant	Zama EOR Project

- Capture over 100 $ktCO_2$
- Capture over 10 $ktCO_2$ from Flue Gas
- Injection over 10 $ktCO_2$ for Storage
- Monitored EOR over 10 $ktCO_2$
- Coalbed Storage over 10 $ktCO_2$

Extent of coverage vs ZEP project matrix

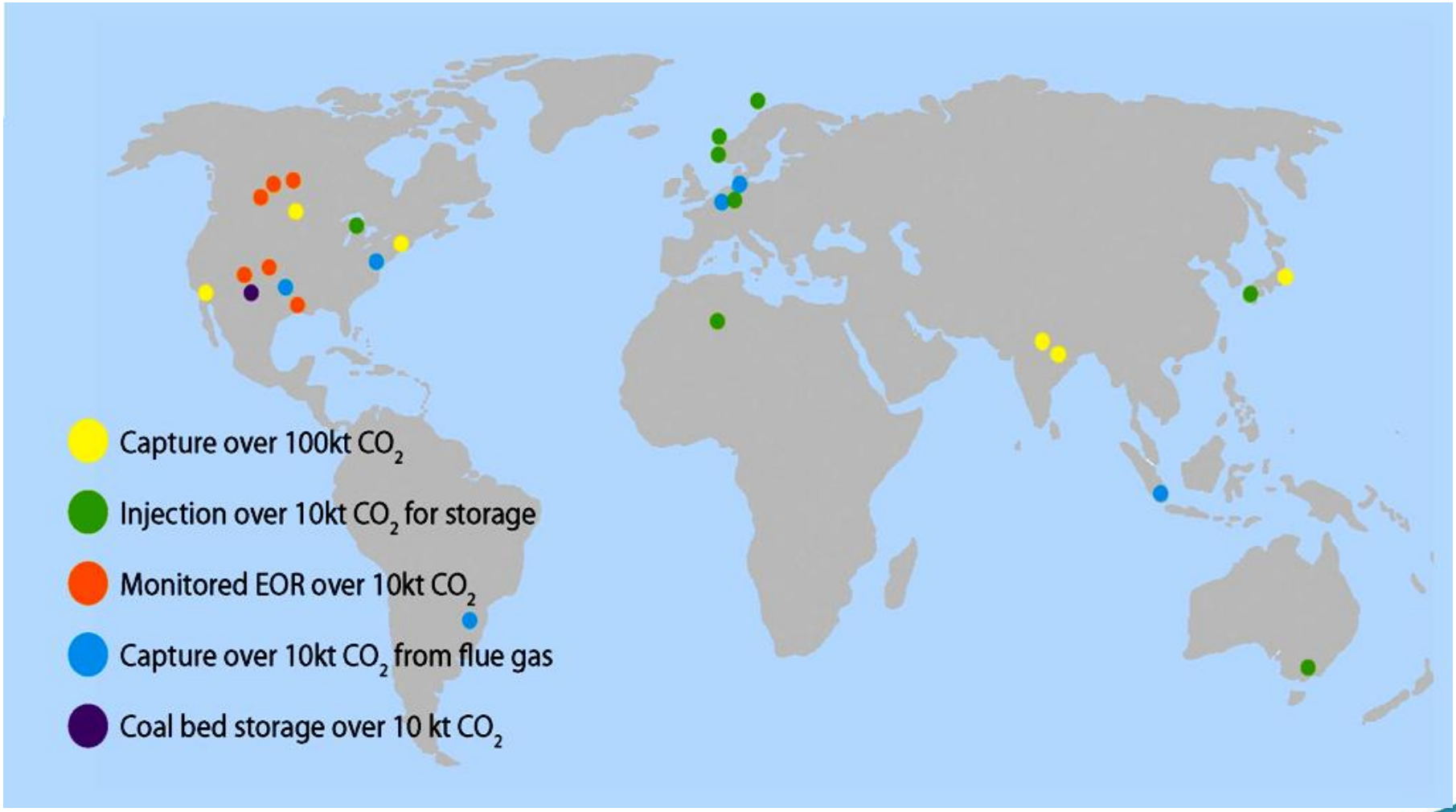
Archetype 1	• Lignite/co-firing with Biomass	• Pre-combustion, variant A	• Cross-border pipeline	• Offshore depleted oil & gas field
Archetype 2	• Gas	• Post-combustion, variant A	• Pipeline	• Onshore structural deep saline aquifer
Archetype 3	• Hard Coal	• Oxy-fuel, variant A	• Ship	• Offshore open deep saline aquifer
Archetype 4	• Hard Coal	• Post-combustion, variant A	• Pipeline	• Onshore depleted oil & gas field
Archetype 5	• Lignite	• Oxy-fuel, variant B	• Pipeline	• Onshore structural deep saline aquifer
Archetype 6	• Hard Coal	• Pre-combustion, variant B	• Pipeline	• Offshore depleted oil & gas field
Archetype 7	• Hard Coal	• Post-combustion, variant B	• Pipeline	• Onshore open deep saline aquifer

Demonstrated in operational large projects

Not demonstrated in operational large projects

Project matrix courtesy of EU Technology Platform for Zero Emission Fossil Fuel Power Plants - ZEP (2008)

Project Locations



Capture Coverage

- 13 capture projects, capturing over 10Mt of CO_2 captured per year
- Technology split:
  - 11 post-combustion
  - 1 pre-combustion
  - 1 oxyfuel
- 9 projects source CO_2 from industrial processes (Natural gas separation, fertiliser production, LNG, hydrogen production)
  - Significant industrial component
- 4 projects in power sector
  - Post combustion capture
    - Castor 1 to 2 tonnes/h (17.5 kt/y)
    - Warrior Run -150 t/d (0.5mt/y)
    - Shady point – 200 t/d (0.6mt/y)
  - Oxyfuel – 9t/h (70 kt/y)

What have we learnt?

- Proprietary issues involved
- Main recipients of knowledge are the capture developers
  - Gained information on how to scale up the technology
  - Material issues/ coping with impurities
- Limited feedback on operational issues
  - Industrial plants are expected to work
  - Pilot operation will fluctuate
- Large body of experience in capture plant operation at appropriate scale in many industry sectors

Scale Up Challenge

- ***Is it an insurmountable problem?***
- Currently for power sector at:
  - Post combustion (~2 MWt)
    - Other plant not included in our analysis
      - Shenhua Pilot, Shanghai, China – 7MW
      - Alstom Chilled Ammonia Pilot, Mountaineer, USA – 54MWt
  - Precombustion
    - 10-20 MWt equivalent industrial syngas
    - ~1000 MWt – Dakota Gasification
  - Oxyfuel (10 MWt)
- ***Manufacturers say it is not.***

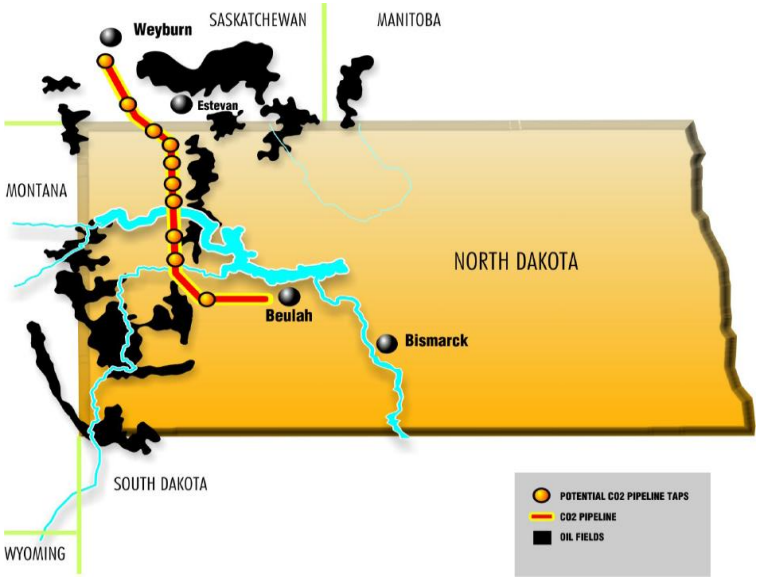
Transport & Compression

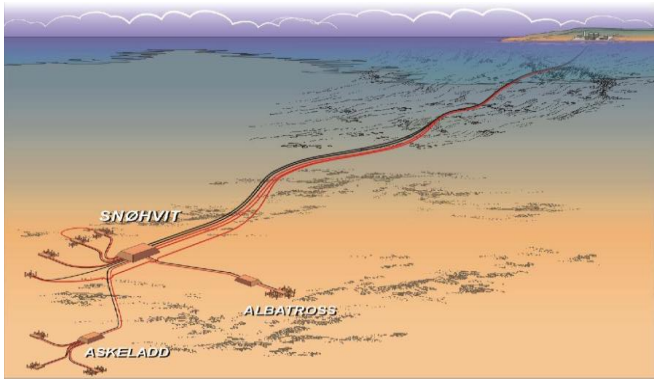
CO_2 flooding in the Permian Basin demonstrating CO_2 sources (yellow), flooded oil fields (green) and associated transmission lines.

Permian Basin, 3000km pipeline network operating since mid 80's

- Largely pure CO_2 from natural sources
  - Some anthropogenic
  - Bellingham Cogen facility
- Established regulatory regime
- Extensive statistical database
  - www.usdot.gov/
  - Number of CO_2 pipeline incidents low and 0 fatalities

Transport & Compression





- 350km overland pipeline built in 1999/2000
  - Novel compressor units
  - H_2S component
    - Added safety issues
    - Seal issues
- Snohvit 160km sub sea pipeline constructed in 2008

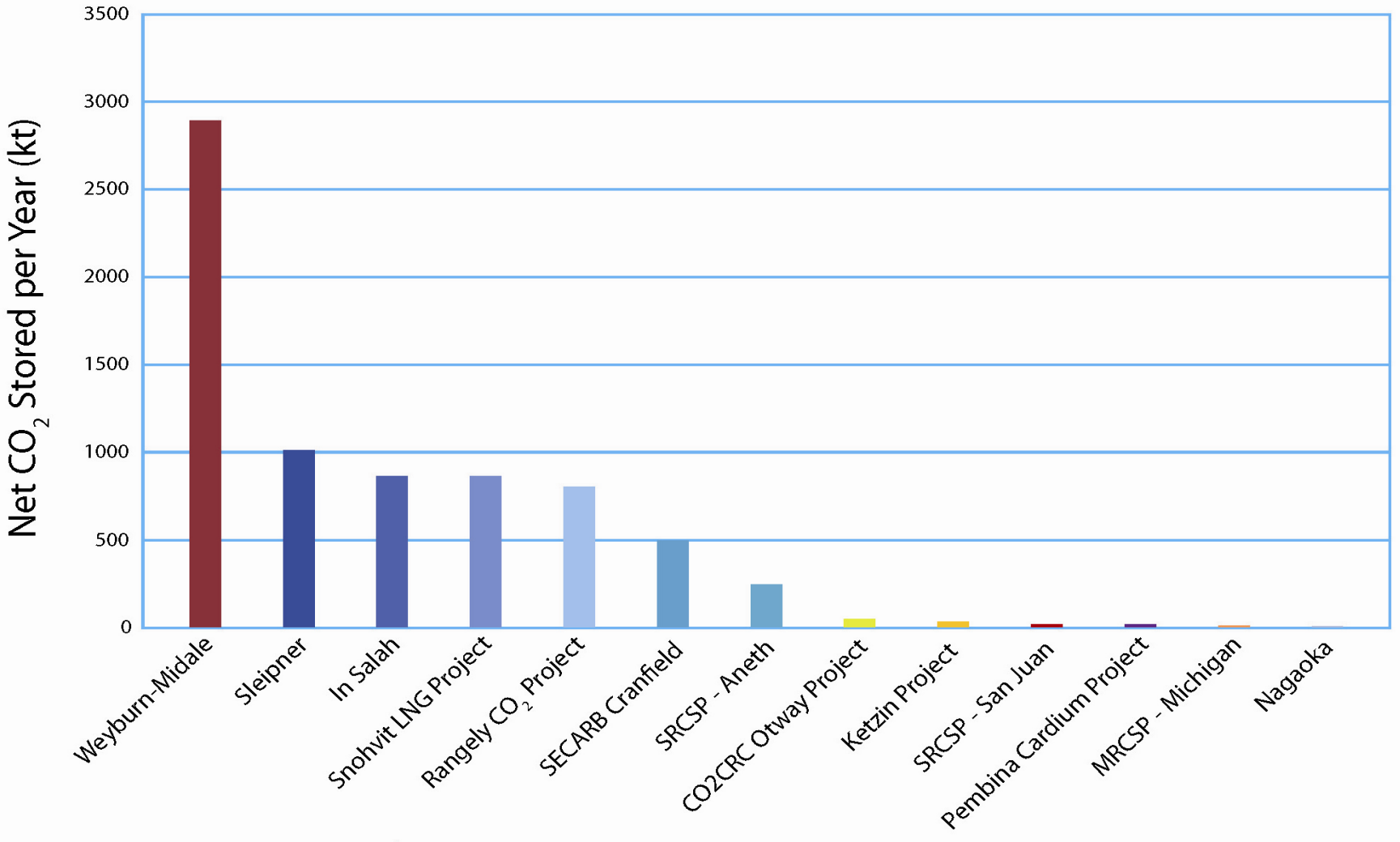
What have we learned about storage?

- Capacity
- Injectivity
- Containment
- Monitorability

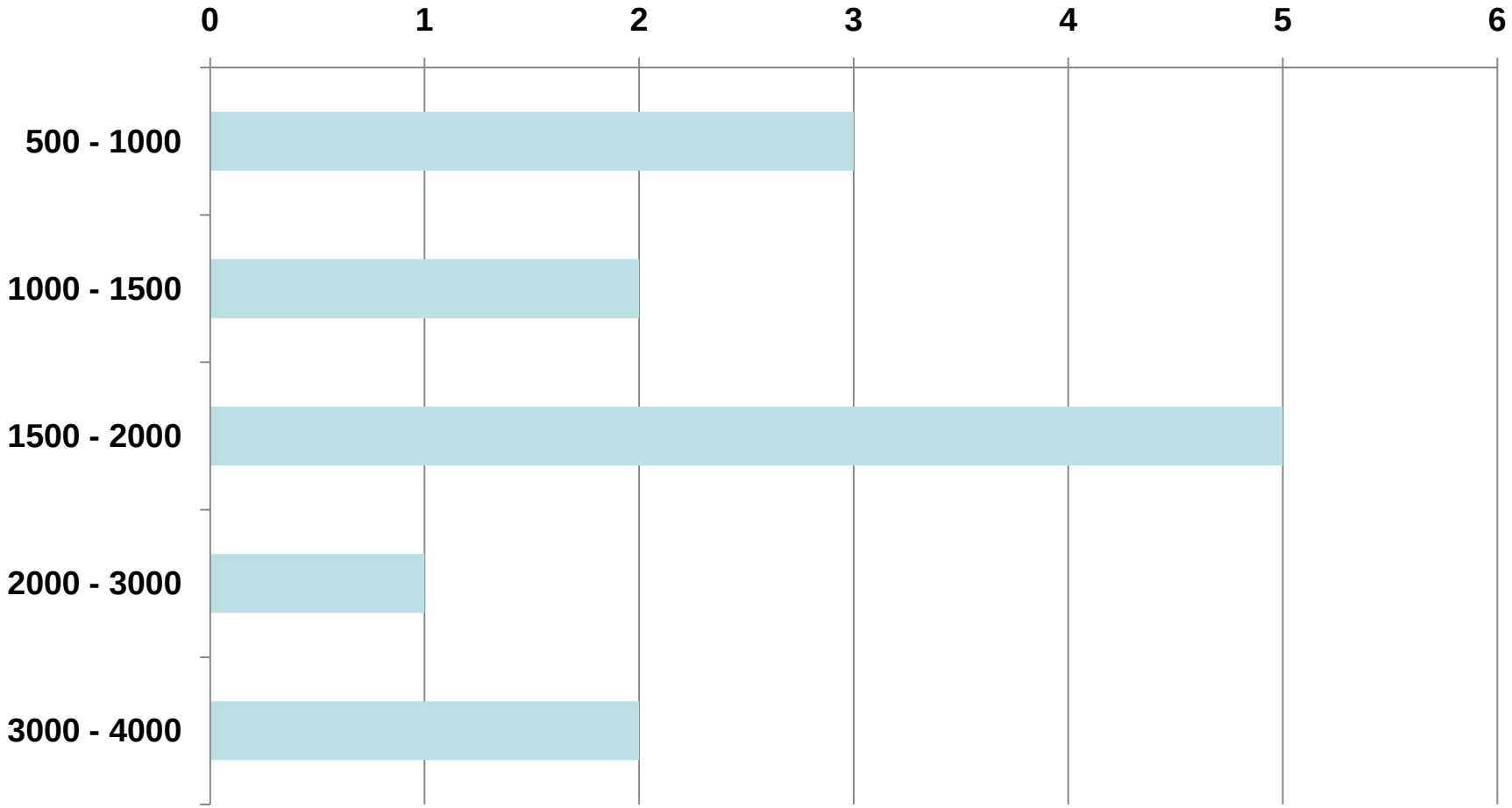
Capacity Estimates (Gt CO_2)

Storage Type	Global (IPCC 2005)	Global (IEAGHG)	USA	Europe
DSF	1,000 – 10,000		3,300 – 13,000	90 – 330
Depleted Gas	680 – 900	160	140	20 - 32
CO2-EOR		65		

Storage rates



Number of Sites by Storage Depth (m)

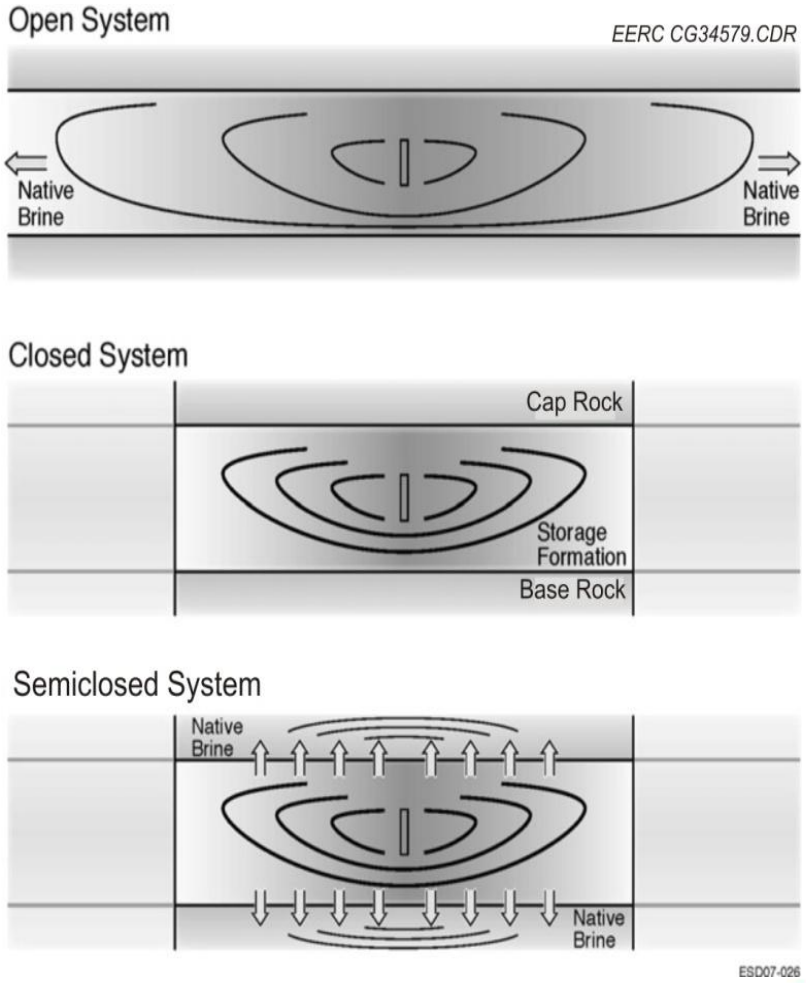


Permeability

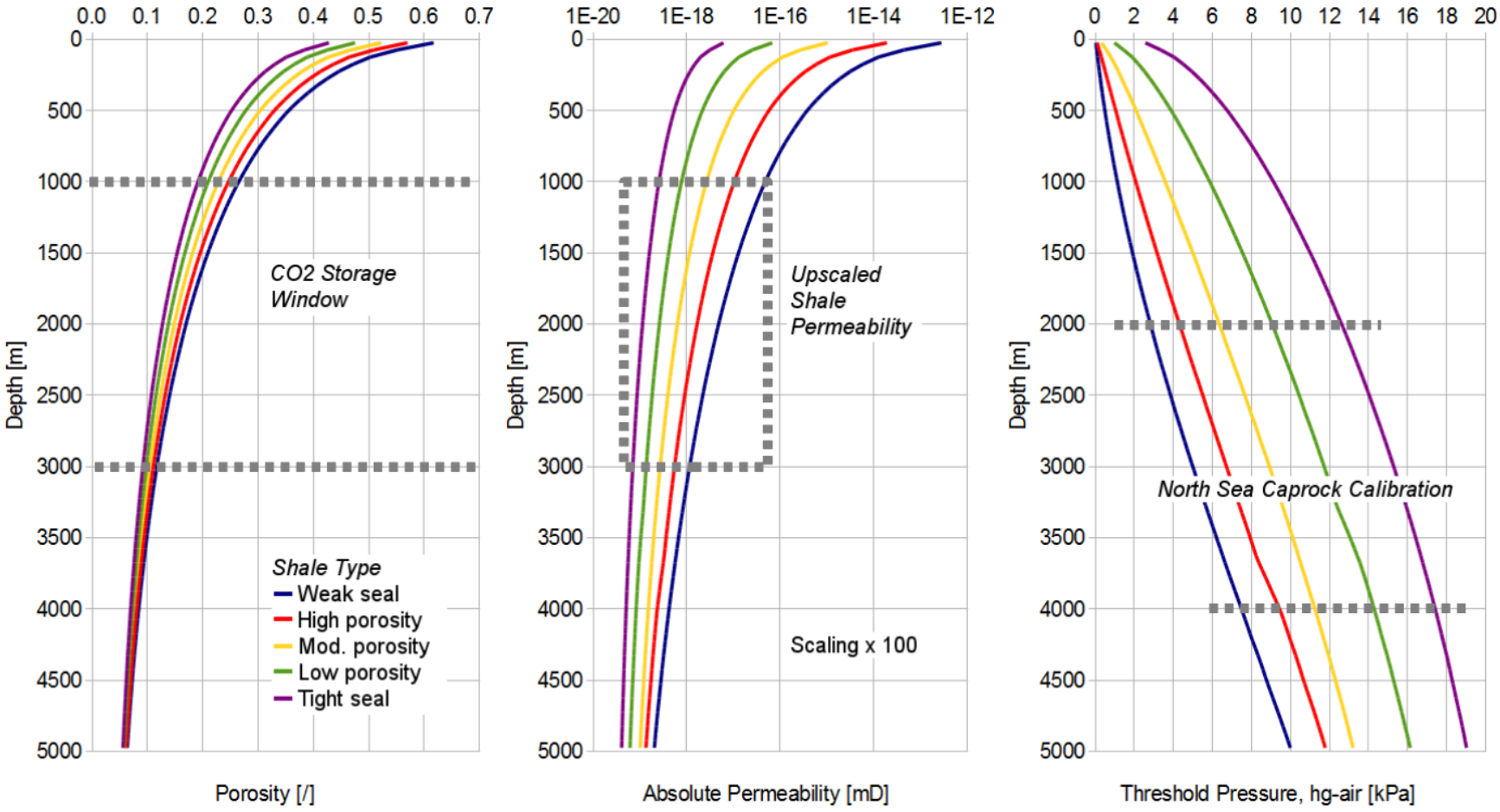
- Two existing 1Mt/annum sites in DSF:
  - Sleipner – 1000mD range permeability
  - In-Salah – 10mD typical permeability
- Possibly at opposite ends of spectrum?
- Other site operators quoted mean permeability between 10’s and 100’s mD
- Other factors also determine injectivity
- Boundary conditions for DSF

Closed versus Open DSF Systems

- **Open systems: regional lateral brine flux, transient pressurisation**
- **Closed systems: rapid loss of injectivity**
- **Semi-closed systems: more realistic?**



Empirical Relationships affecting Regional Shale Permeability



Summary – Injectivity

- CO_2 has been injected into:
  - High permeability sand bodies offshore (Sleipner)
  - Low permeability sandstone and carbonate reservoirs
    - On shore (In-Salah, Weyburn etc)
    - Off shore (K12-B)
  - Depths ranging from 800 to >3000m
- Some injection problems identified early at some sites
  - No insurmountable problems reported

Monitoring technique coverage

- 2D seismic
- 3D seismic
- 4D seismic
- Vertical seismic profiling
- Cross-well seismic
- Electrical conductivity
- Microseismic
- Passive seismic
- Soil gas sampling
- Detector arrays
- Eddy covariance
- Observation wells
- Time lapse microgravity
- Well temperature and pressure
- Well logs
- Tracers
- Ground water geochemistry
- Interferometry
- Satellite imaging
- Tilt meters

Common Monitoring Techniques

Technique	No of Sites	Positive comments	Negative comments
DH temp/pressure	11		
Surface seismic	10	2	3
Soil gas	9		
Geochemical	8	1	
VSP	8		1
Microseismic	7		1
Gravity	4		1
Crosswell seismic	3	1	1
Electrical Conductivity	3	1	
Satellite	3	1	

Comments on Surface Seismic (*site specific*)

- "Seismic is unlikely to be cost-effective in the long run"
- "Glacial till cover made seismic difficult to use"
- "A recent attempt at 3D seismic did not reveal useful information – so we do not consider effective for monitoring CO_2 floods"
- "The seismic survey clearly demonstrated an ability to detect anomalies in the reservoir caused by CO_2 invasion"
- "Detecting pressure propagation using seismic signals is sometimes easier than detecting the CO_2 itself"
- "Pre-injection surface seismic MIGHT have made subsequent seismic more useful"

What happens next

- Now we have gained trust we are:
  - Going back for targeted information on specific issues
- Then in 2011 we will repeat the exercise again
  - To gain additional learning
- Consolidate the information gained
- Develop key messages that can be used to convey what we know to stakeholders

Recent and Current IEAGHG CO_2 Storage Studies

- Storage Capacity Coefficients
- Global Storage Potential for CO2-EOR
- Injection Strategies
- Brine Displacement and Pressurisation
- Potential Impacts on Groundwater Resources
- Effects of Impurities
- Storage Resource Gap Analysis
- Caprock Systems for Storage
- Storage Cost Calculator

We have work to do !

- The populace seem to be becoming more sceptical about climate change
  - Politicians need to act
- Public opposition has stopped a number of CCS projects already
  - Scientific community and industry

Thank you for your attention